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Manuscript Title: A reliable testing battery for assessing physical qualities of elite academy rugby league players.

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27 **ABSTRACT**

28 This study assessed the inter-day reliability of a testing battery for the assessment of
29 physical qualities of rugby league players. Fifty players (age 17.1 ± 1.1 years; stature
30 181.3 ± 6.3 cm; body mass 89.0 ± 11.6 kg) from three Super League academies
31 participated in this study. Tests of countermovement jump performance, 10 and 20 m
32 sprint performance, change of direction, medicine ball throw and a modified Yo-Yo
33 Intermittent Recovery Test Level 1 (prone Yo-Yo IR1) were completed on three
34 separate occasions. Between-day intraclass correlation coefficient, typical error (TE),
35 coefficient of variation (CV) and the smallest worthwhile change (SWC) were
36 calculated to determine the reliability and sensitivity of each measure. Individual
37 tests (except medicine ball throw) were not systematically different between trials
38 ($P > 0.05$), with an inter-day variability that was $< 10\%$. In all instances, the TE was
39 larger than the calculated SWC change although variability was less than that
40 typically observed after a training intervention or specific training period (i.e.
41 preseason). Using a magnitude-based inference approach, we present the required
42 change for all performance tests to be 75% confident the change is beneficial. This
43 simple and time efficient testing battery is sufficiently reliable to detect previously
44 observed changes in a range of physical qualities of rugby league players.

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51 **Key Words:** measurement, performance, team sport, testing

52 INTRODUCTION

53 Rugby league is an intermittent collision sport that requires players to perform
54 frequent high-intensity movements such as high-speed running, sprinting, and
55 tackling interspersed with periods of low-intensity activities such as standing,
56 walking, and jogging (14). As such, players are required to possess highly developed
57 physical qualities including speed, strength, power, agility and endurance as well as
58 skill and tactical awareness (4,15,16). The assessment of these physical qualities can
59 provide objective data that can be used to ensure players can meet the demands of
60 the sport (15), evaluate adaptation to training programmes (14), identify talent
61 (13,14), monitor player development (37) and predict player selection (4).

62

63 Acceleration and sprint ability is frequently assessed by rugby league practitioners
64 and used in combination with body mass to determine a player's sprinting
65 momentum, evaluate training adaptation and monitoring development (37).
66 Furthermore, acceleration and sprinting appears to be an integral component for
67 successful performance in rugby league, with players performing on average 35 ± 2
68 sprints per match (17). These actions often occur during critical passages of play
69 such as scoring or conceding a try (19). Consequently, rugby league players' sprint
70 performance is typically measured over 10, 20, and 40 meter (m) distances; thereby
71 encompassing a measure of acceleration (0-10 m) and maximal speed (10-40 m)
72 (19). Acceleration and sprint ability are reported to improve from off-season to mid-
73 season in junior rugby league players (14) and can differentiate between playing
74 standards (e.g. professional, semi-professional and amateur) (14). Therefore, the
75 ability to assess these qualities in the context of a practically meaningful change in
76 acceleration and maximal speed is essential for rugby league practitioners.

77

78 The ability to change direction is also an essential quality in rugby league that
79 differentiates between playing standards (13). Several change of direction tests have
80 been used in rugby league; these include the Illinois agility test (13), 'L'-run (14,20),
81 and 505 agility (20). However, no rugby-league specific test is universally advocated
82 and those used typically focus on change of direction angles above 90° rather than
83 incorporating 'cutting'; a skill often performed during rugby league match-play (20).

84

85 Well-developed muscular power in rugby league has been associated with successful
86 skill execution (38) and reduced post-match fatigue (29). Accordingly, practitioners
87 at all standards of the game must be able to assess power using practical methods of
88 assessment. Several methods have been employed to assess upper- and lower-body
89 power in rugby league players, including, but not limited to, the jump squat (5),
90 countermovement jump (CMJ) (38), medicine ball throw (36) and bench press throw
91 (5). While the medicine ball throw and vertical jump do not provide direct measures
92 of muscle power, both tests are valid measures of this physical quality (28) and are
93 easy and quick to administer. Scores obtained using the medicine ball throw and
94 CMJ can differentiate between national and regional youth rugby league players
95 (36).

96

97 The Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) and 30-15 Intermittent Field
98 Test are often used to assess intermittent running capacity of rugby league players
99 (1,32). Using the Yo-Yo IR1 to differentiate between low- and high-fitness players,
100 Johnston et al. (29) reported that the high-fitness group covered significantly greater
101 distances and high- and very high-speeds during match-play as well as improved

102 recovery. In contrast, no significant relationship was observed between Yo-Yo IR1
103 and measures of physical match performance in semi-professional rugby league
104 players (21). It is known that the collision contributes to a greater physiological load
105 (31), which might result in a disassociation between physical match performance and
106 a running-based intermittent field test (3). As such, we have introduced an up-and-
107 down action at the start of each shuttle to assess the players' ability to get up after
108 the tackle and join play. This modified Yo-Yo IR1 test is associated ($r = 0.48-0.78$)
109 with a player's ability to maintain relative distance, mean speed, high metabolic
110 power, and sprint performance during a simulated match (unpublished data). We
111 therefore believe that the prone Yo-Yo IR1 provides a valid measure of rugby-
112 specific high-intensity running capacity.

113

114 The use of a standardised testing battery that is economical, easy to administer,
115 requires the minimum of technical equipment or expertise would be useful for rugby
116 league practitioners to accurately monitor changes in performance due to training
117 adaptations (37). Further, due to the range of tests that have been incorporated into
118 testing batteries, it is difficult to compare players between age-grades, clubs and
119 countries, and as such, a standardised battery that is easily replicable could be useful
120 (37). It is important to ensure that all measurements made as part of a testing battery
121 are reliable (2). The reliability, expressed as a coefficient of variation, for the 10 m
122 (3.05%) and 20 m (1.82%) sprint times (11), CMJ height (5.2%) (9), Yo-Yo IR1
123 (8.7%) (35) and pre-planned agility (1.9-2.5%) (20) has been reported using team
124 sport athletes. However, few studies have established the reliability using only rugby
125 league players, which is important given the large differences in physical attributes
126 (i.e. body mass) compared to other team sports. Furthermore, previous reliability

127 studies have typically used small sample sizes (< 50) over two repeated trials.
 128 Hopkins noted that to achieve reasonable precision for estimates of reliability,
 129 approximately 50 participants and at least three trials are required (24).
 130 Understanding the reliability of a range of performance tests used in rugby league
 131 and the extent to which players require habituation (as determined by a third trial)
 132 would therefore be practically meaningful. Accordingly, this study sought to assess
 133 the inter-day reliability, in the context of meaningful changes in performance, of a
 134 standardised testing battery that can be used to assess the physical qualities of rugby
 135 league players.

136

137 **METHODS**

138 *Experimental Approach to the Problem*

139 The repeated measure design required participants to complete the same battery of
 140 tests on three separate occasions with 7.9 ± 3.8 (range 5-14) days between visits. All
 141 visits took place during each club's pre-season with players performing no work-
 142 based or leisure-time physical activity in the 24 h before data collection. On arriving
 143 at the club's own training facility, measures of stature (SECA stadiometer, Leicester
 144 Height Measure, Hamburg, Germany) and body mass (SECA scales, 813, Hamburg,
 145 Germany) were recorded before performing a CMJ, 10 and 20 m sprint test, change
 146 of direction test, medicine ball throw and modified Yo-Yo IR1 (prone Yo-Yo IR1).
 147 All tests were carried out by the same researcher and were performed on an outdoor
 148 synthetic grass pitch (3G all-weather surface) at the same time of day (± 2 h), with a
 149 mean temperature during the three trials of $10.8 \pm 3.8^{\circ}\text{C}$. Participants were asked to
 150 refrain from caffeine 12 hours before testing, and although not measured, were
 151 advised to attend each session well-hydrated. Participants were required to wear the

152 same clothing and footwear (studded boots) for each visit and completed a
153 standardised warm up before being divided into two groups. Group one completed
154 the CMJ and sprint tests, while group two completed the medicine ball throw and
155 change of direction test. The groups then swapped and came together to complete the
156 prone Yo-Yo IR1. The test order was standardised for all visits and was completed
157 within ~75 min.

158

159 ***Subjects***

160 With institutional ethics approval, 50 academy rugby league players from three
161 professional clubs playing in the Under-19s Super League competition (age 17 ± 1
162 years; stature 181.3 ± 6.3 cm; body mass 89.0 ± 11.6 kg) participated in the study.
163 Players were informed of the benefits and risk associated with this study before
164 providing written informed consent and completing a pre-test health questionnaire
165 Parental consent also provided for all participants <18 years old. Players were free
166 from injury at each time point of the study, which was confirmed by the respective
167 club's medical team.

168

169 ***Procedures***

170 *Countermovement Jump*

171 Participants completed four countermovement jumps (CMJ) comprising two using
172 their arms (with) to determine the influence of the arm swing on measures of
173 reliability and two with hands placed on the hips (without) in an attempt to
174 standardise the jump. A period of 2-minutes recovery was permitted between jumps.
175 Participants started upright in their playing boots before flexing at the knee to a self-
176 selected depth and then extending into the jump for maximal height keeping their

177 legs straight throughout. Jumps that did not meet the criteria were not recorded and
178 participants were asked to complete an additional jump. Jump height was recorded
179 using a jump mat (Just Jump System, Probotics, Huntsville, Alabama, USA) and
180 corrected (12) before peak height was used for analysis.

181

182 *Sprint performance and momentum*

183 Sprint performance was measured using single beam electronic timing gates
184 (Brower, Speedtrap 2, Brower, Utah, USA) positioned at 0, 10 and 20 m. The timing
185 gates were placed 150 cm apart and at a height of 90 cm for all trials. Participants
186 began each sprint from a two-point athletic stance with their driving foot placed 30
187 cm behind the start line. Participants performed two maximal 20 m sprints recorded
188 to the nearest 0.01 s with 2-minutes recovery between each. The best 10 and 20 m
189 sprint times were used for analysis. Momentum was calculated by multiplying body
190 mass by mean velocity (distance / time) over the best 10 and 20 m time recorded
191 (11).

192

193 *Change of direction*

194 Change of direction performance was measured using single beam electronic timing
195 gates (Brower, speedtrap 2, Brower, Utah, USA) placed 150 cm apart and at a height
196 of 90 cm, and required participants to complete two trials (left and right) consisting
197 of different cutting manoeuvres over a 20 x 5 m course (Figure 1). Participants
198 started when ready from a two-point athletic stance with their driving foot placed 30
199 cm behind the start line. One trial was performed on the left, the timing gates were
200 then moved, and a second trial was performed on the right in a standardised order

201 before times were combined. Failure to place both feet around each cone resulted in
 202 disqualification and participants were required to repeat the trial.

203

204 *Medicine ball throw*

205 Whole-body muscle function was assessed by having participants throw a medicine
 206 ball (dimensions: 4 kg, 21.5 cm diameter) striving for maximum distance.
 207 Participants began standing upright with the ball above their head. They then
 208 lowered the ball towards their chest whilst squatting down to a self-selected depth
 209 before extending up onto their toes and pushing the ball as far as possible. Feet
 210 remained shoulder width apart, stationary and behind a line that determined the start
 211 of the measurement. The distance was measured to the nearest centimetre using a
 212 tape measure from the line on the floor to the rear of the ball's initial landing
 213 position. A trial was not recorded if the participant stepped into the pass, jumped or
 214 if the ball landed outside of the measuring area and, in such cases, an additional trial
 215 was completed. Participants completed two trials separated by 2-minutes recovery
 216 with the furthest distance used for analysis.

217

218 ****Insert Figure 1 about here****

219

220 *Prone Yo-Yo Intermittent Recovery Test Level 1*

221 The prone Yo-Yo IR1 was used to measure high-intensity intermittent running
 222 capacity and required participants to complete as many 40 m shuttles as possible
 223 with a 10 s active recovery (walking) between shuttles (6). Running speed for the
 224 test commenced at 10 km·h⁻¹ and increased 0.5 km·h⁻¹ approximately every 60 s to
 225 the point at which the participants could no longer maintain the required running

226 speed. Participants were required to start each shuttle in a prone position and were
227 allowed two practice shuttles before starting the test. The final distance achieved was
228 recorded after the second failed attempt to meet the start/finish line in the allocated
229 time.

230

231 ***Statistical Analysis***

232 Data are presented as mean \pm SD. The distribution of each variable was examined
233 using the Shapiro-Wilk normality test and homogeneity of variance was verified
234 with the Levene test. To determine if there was a systematic difference between
235 trials, separate repeated measure ANOVA were performed with alpha set at 0.05 and
236 a *non-significance* interpreted as a lack of systematic performance improvement or
237 decrement rather than no difference between trials. In the presence of a statistically
238 significant difference, *post-hoc* paired samples *t*-tests were performed with
239 Bonferroni adjustment. To determine the reliability of each measure, intraclass
240 correlation coefficient (ICC) with 95% confidence limits (CL), and typical error (TE)
241 and coefficient of variation (CV%) with 90% CL were used. TE was calculated as
242 the standard deviation of the differences between trials divided by the $\sqrt{2}$ and the
243 CV% as $(TE / \text{grand mean}) \times 100$. Standardised changes of different magnitudes
244 were calculated to provide context for the observed inter-day variation in
245 measurements. A smallest worthwhile change (SWC) in performance was considered
246 as $0.2 \times$ the pooled standard deviation for each variable (7,27). To ascertain the
247 performance improvement required to be 75% confident the change was beneficial
248 (22), a magnitude-based inferences approach was used using the SWC and TE for
249 each variable (25) and reported as the “required change”. These required
250 performance improvements are presented in the results and are later used as an

251 'analytical goal' (i.e. the observed reliability must be sufficient to allow confident
 252 detection of feasible or previously observed changes in performance). Statistical
 253 analyses were conducted using SPSS for Windows (Version 22.0, 2013) and a pre-
 254 designed spreadsheet (26).

255

256 **RESULTS**

257 There were no systematic changes in stature or body mass across the three trials.
 258 Inter-day reliability of the performance tests across the three trials is presented in
 259 Table 1. While none of the variables had a TE less than the SWC all variables had a
 260 TE less than that typically observed after a preseason season training period or
 261 intervention. All tests had a CV of less than 10% with the agility test (2.4%) and 20
 262 m sprint tests (3.6%) demonstrating the lowest and prone Yo-Yo IRT1 (9.9%) the
 263 highest variability. Intraclass correlation coefficient ranged from 0.74 and 0.98. The
 264 required change for all performance tests with 75% confidence are presented in
 265 Table 1.

266

267 *****Insert Table 1 about here*****

268

269 Between day comparisons indicated that medicine ball throw distance was greater on
 270 trial 2 ($P<0.05$) compared to trials 1 and 3. Performance during all other tests did not
 271 systematically change across trials ($P>0.05$). Specific comparisons of variability
 272 between days indicated that reliability was, for the most part, best when comparing
 273 trials 1 and 2 (Table 2).

274 *****Insert Table 2 about here*****

275

276 **DISCUSSION**

277 The purpose of this study was to determine in inter-day reliability of a testing battery
278 for the assessment of physical qualities. Overall, the variability exceeded the
279 statistically determined 'smallest worthwhile change' in performance, but was less
280 than that typically observed after a preseason training period or intervention. This
281 suggests the testing battery used can detect a meaningful change with 75%
282 confidence comparable that typically observed or that is considered feasible. The
283 testing battery was quick and simple to administer, and required minimal equipment
284 and expertise, thus enables rugby league practitioners to use our results when
285 interpreting differences between players and for assessing the effectiveness of
286 training programmes.

287

288 The reliability of 10 and 20 m sprint times was similar to that previously reported
289 (4.2% cf. 3.1% and 3.6% cf. 1.8%, respectively) (11). However, it is important to
290 note that the study by Darrall-Jones et al. (11) used a combination of rugby league
291 and rugby union players who likely present different anthropometric characteristics
292 and running mechanics (10). The TE for 10 and 20 m sprint times was greater than
293 the SWC for both distances; however, when considering the reliability of sprint
294 performance against previously reported improvements, both distances appear
295 sensitive enough to detect the observed change (TE 0.08 cf. 0.13 s; CV 4.2% cf.
296 7.3%) after an 8-week preseason training period in professional rugby league players
297 (8). Indeed, using a magnitude-based inferences approach our analysis revealed that
298 an individual change was lower than the improvement observed over 10 (0.11 cf.
299 0.13 s) and 20 m (0.15 cf. 0.18 s) after a 8-week strength and power preseason
300 training block (8). Inter-day comparisons for 10 and 20 m sprint performance were

301 best between trials 1 and 2, suggesting that habituation to sprint tests is not required
302 with academy rugby league players.

303

304 To the authors' knowledge, this is the first report of between-session reliability for
305 momentum in professional rugby league players. The TE for 10 and 20 m
306 momentum was greater than the SWC. Nonetheless, based on the mean body mass
307 (96.2 ± 11.11 cf. 97.7 ± 11.13 kg), 10 m sprint times (1.78 ± 0.07 cf. 1.65 ± 0.08 s)
308 and 20 m sprint times (3.03 ± 0.09 cf. 2.85 ± 0.11) reported by Comfort et al. (8)
309 before and after 8 weeks of preseason strength and power training, changes in
310 momentum would be of greater magnitude than the TE (52 and 51 cf. $25 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}$,
311 respectively) and CV% (9.6 and 8.0 cf. 5.5%, respectively) reported in this study.
312 Our results revealed that a 34 and 19 $\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$ improvement over 10 and 20 m,
313 respectively, is required to be 75% confident the change is meaningful (22), which
314 could feasibly be achieved through a reduction in sprint times or an increase in body
315 mass. These results, combined with the inter-day comparisons, suggest that
316 momentum could be a useful measure for practitioners in rugby league to assess the
317 combined effect of an individual's body mass and sprint capability over 10 m and 20
318 m.

319

320 Our data indicate that the CMJ is a reliable measure of lower-body muscle function
321 and is improved when a participant's hands remain on their hips (CV% = 5.9% cf.
322 6.2%). The use of an arm swing during jumping can improve jump height due to an
323 increased release velocity and centre of mass (30). The use of arms allows the athlete
324 to use energy in the elbow, shoulder and hip to increase the kinetic energy at take-off
325 and increase the vertical 'pull' on the trunk (30). However, with the added

326 movement complexity, the arm swing increases the within-participant variability
327 between jumps. Our results also indicate that reliability was best for CMJ with arms
328 between trials 2 and 3 suggesting that habituation is required. Overall, the CV% for
329 CMJ without arms are similar to that reported by Cormack et al. (9) and reliability is
330 smaller than typical improvements in jump performance observed in young (7.2%)
331 but not senior (4.5%) team sport players after preseason training (16). Furthermore,
332 our data revealed that the TE is sufficient to confidently detect a change (3.4 cm)
333 which is less than that previously observed in junior rugby players after a 14-week
334 preseason training programme (~4.2 cm) (16). Inter-day reliability for CMJ with
335 arms was best between trials 1-2 suggesting that habituation is not required when
336 using academy rugby league players.

337

338 The medicine ball throw has been used as a measure of whole-body muscle function
339 in rugby players that is valid and reliable (34). However, it is important to note that
340 several techniques have been adopted. The present study required participants to
341 throw a medicinal ball from the chest in a standing position to better replicate the
342 upper-body actions of rugby league, e.g. a 'hand-off'. The variability was greater
343 than the SWC in medicine ball throw performance, whilst an increase of 0.7 m in
344 distance would be required to ensure an improvement is beneficial with a certainty of
345 75% (22). As the TE was greater than the SWC, practitioners who want to use the
346 medicine ball throw should consider incorporating this into training to regularly
347 assess whole-body power (23). The reliability of the medicine ball throw was likely
348 influenced by use of the lower-body as well as the lack of control over the release
349 angle. Notwithstanding this, using the results of Speranza et al. (33) who reported an
350 increase in plyometric push-up performance of 11.9% after an 8-week preseason

351 training period in semi-professional rugby league players, the medicine ball throw
352 could detect large changes (>0.7 m) in whole-body muscle function, albeit further
353 research is required to confirm this.

354

355 Our results indicated good reliability for the change of direction test, albeit the
356 variability exceeded what is considered the SWC in left, right and total time.
357 Nonetheless, the variability is less than the typical change (junior = 17.7% and senior
358 16.3%) in 'L run' times after a 14-week preseason period using rugby league players
359 (16). To achieve 75% confidence, an improvement of -0.31, -0.35 and -0.67 s for left,
360 right and total change of direction times is required. However, directly comparing
361 the absolute change required against that previously observed is difficult given the
362 novelty of the test used and further research might reaffirm this. Inter-day
363 comparisons revealed that the reliability was similar between all trials but was lowest
364 between days 1 and 3 for left, right and total time, suggesting habituation to this test
365 might be required. The change of direction test used in this study assesses a player's
366 ability to change direction over several angles that better replicates the movement
367 characteristics during intermittent team sport.

368

369 The variability associated with the prone Yo-Yo IR1 was greater than that
370 considered to be the SWC in performance. The required change in individual
371 performances when accounting for the TE corresponded with a 120 m (or 3 shuttles)
372 increase in performance to be considering meaningful (22). To date, no research has
373 reported the change in Yo-Yo IR1 performance after a training intervention or
374 preseason training period using rugby league players. However, Bangsbo et al. (6)
375 reported changes of between 12.7-31.1% after 6- to 12-weeks of soccer-specific,

376 interval and repeated sprint training, a change that could confidently be detected with
377 our reported TE. Whilst practitioners might use the reliable Yo-Yo IR1 for
378 assessment of running alone, the modified Yo-Yo presented here offers an
379 opportunity to assess high-intensity intermittent running incorporating a match
380 specific-task with sufficient reliability.

381

382 While every effort was made to reduce the contribution of fatigue by conducting
383 tests on the day after a scheduled rest day, collecting data during pre-season means
384 players were likely to be subject to higher training volumes than other times of the
385 year (18). Therefore, it is possible that some residual fatigue from training several
386 days beforehand each test might have contributed to a larger variability between
387 trials. Future research might consider using perceptual measures of fatigue to
388 quantify recovery status when establishing the inter-day reliability of this testing
389 battery. This notwithstanding, our data are taken from a large sample size within a
390 professional training environment that reflects the real-world variability in
391 performance. It also noteworthy that the test order was different for the two groups
392 although results (not reported) revealed minimal difference in reliability (for
393 example, 10 m sprint time: group 1; TE = 0.08 and CV = 4.5%, and group 2; TE =
394 0.08 and CV = 3.9%). We would, however, recommend that practitioners perform the
395 testing in the following order to minimise any influence of residual fatigue on test
396 performance: warm up, 10 and 20 m sprint, change of direction test, CMJ, medicine
397 ball throw, and prone Yo-Yo IR1.

398

399

400 **PRACTICAL APPLICATIONS**

401 Our results support the interpretation of tests of physical qualities and provide a
402 novel approach using magnitude-based inferences. All performance tests
403 demonstrate acceptable reliability in the context of detecting a typical change after a
404 training intervention and/or preseason training period using rugby league players.
405 However, the variability associated with each performance measure, when tested in
406 the 'field', was greater than that required to detect the smallest worthwhile change in
407 performance. Between-trial comparisons revealed that, for the most part, habituation
408 was not required when using rugby league players. Due to the large between-trial
409 variation during the medicine ball throw, researchers might wish to investigate the
410 reliability and sensitivity of the medicine ball throw when controlling variables such
411 as release angle. Our results also revealed that the reliability of the CMJ was
412 improved when participants placed their hands on their hips and that the between-
413 trial reliability of momentum was acceptable and can be used to assess the
414 relationship between body mass and 10 and 20 m sprint capacity. Future research
415 should establish the usefulness of this testing battery to monitor changes in players'
416 physical qualities over a season or during specific training periods (e.g. preseason).
417 Where time and resources are scarce, this testing battery can be conducted in a
418 relatively short time frame (<75 min), does not impact on other training and requires
419 minimum specialist equipment.

420

421

422

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Figure 1. Schematic representation of the pre-planned agility test.